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GROUND WATER IN THE DELAWARE RIVER VALLEY

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GROUND WATER IN THE DELAWARE RIVER VALLEY

H.C. Barksdale and S.M. Lang,[1] J.M. ASCE

In the Delaware River valley, major emphasis has been placed upon surface-water supplies because of the great quantities of water that can be easily obtained from surface streams. Furthermore, the recent cases before the United States Supreme Court dealing with diversion of water from the Delaware Valley have focused the public eye upon surface-water problems. Nevertheless, the many aquifers of the valley furnish large and important supplies of ground water. The size, value, and importance of these supplies will undoubtedly increase with the industrialization of the valley and the increasing need for readily available supplies of good water of uniform quality and temperature.

Ground-Water Hydrology

Ground water, like all other fresh water available for human use, is derived essentially from precipitation. It is stored in and moves through interstices of the rock materials that form the upper part of the earth's crust. However, only a portion of the water that is present beneath the land surface is available for human use. Such factors as porosity, specific yield, permeability, and transmissibility, as well as the availability of recharge and the danger of contamination, affect the quantity and quality of water that a water-bearing formation can yield.

Porosity is a measure of the total voids or interstices in a rock. It is expressed quantitatively as a percentage of the total volume of the rock, including both solid material and voids. The specific yield is the quantity of water yielded by gravity drainage from saturated water-bearing material and is likewise expressed as a percentage of the total volume of the material drained. The specific yield is always less than the porosity because some water is held in the rock by molecular attraction. The quantity of water retained by the material against the pull of gravity is termed the specific retention, and it also is expressed as a percentage of the total volume of the material. The sum of the specific yield and the specific retention of a saturated material is equal to its porosity.

The permeability of a water-bearing material is a measure of its ability to transmit water from points of recharge to points of discharge. The field permeability is defined as the rate of flow of water in gallons per day through a cross-sectional area of the material of 1 square foot under a unit hydraulic gradient at the prevailing temperature of the ground water. The transmissibility of an aquifer is equal to its average field permeability multiplied by its saturated thickness in feet.

In an area in which there is no ground-water development, the water supply in the aquifers is in approximate equilibrium so that over a long enough period the recharge to the aquifers counterbalances the discharge from them. However, in an area in which there are artificial withdrawals of ground water,

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the normal recharge-discharge balance is disturbed, producing lowering of water levels and a tendency toward a new and different balance. A new balance may be achieved without exceeding the capacity of the aquifer by decreasing the natural discharge by a quantity equal to that being pumped, by increasing the recharge, or by a combination of these two processes. Since the rates of precipitation and infiltration are not easily manipulated, increased recharge is generally achieved by inducing surface water to move into the aquifer. This may cause changes in the quality of the ground water. If a new balance is not obtained, water levels will decline until the aquifer is dewatered or until the cost of pumping becomes prohibitive and the rate of withdrawal is decreased.

In the Delaware River valley, there are large areas where the ground water resources are essentially undeveloped. In these areas, ground water is being discharged into surface streams almost continually and maintains their dry-weather flow. A substantial part of the total streamflow is thus derived from ground water discharge. On the other hand, in some areas adjacent to the streams, the withdrawal of ground water has reversed the normal hydraulic gradients within the aquifers so that they are now receiving recharge from the streams. This is especially true along some reaches of the Delaware River below Trenton.

Geology

The rocks that form the upper part of the crust of the earth are solid throughout in few places, if anywhere. Generally, they contain numerous voids, the receptacles that hold the vast quantities of water that is found below the surface of the land. There are, of course, many kinds of rock, and they differ greatly in the number, size, shape, and arrangement of their voids and, consequently, in their capacities to store and transmit water. The occurrence and availability of ground water in any region is determined by the character, distribution, and structure of the rocks it contains—that is, by its geology. No attempt is made here to present anything but a very general discussion of the geology of the Delaware River valley. However, a thorough knowledge of the geology of any given locality is essential in evaluating its ground water potentialities.

The lower part of the Delaware River valley lies in the Atlantic Coastal Plain, within which the materials at the surface and, except at its northwestern border, for considerable depths below the surface, are predominantly unconsolidated sands, gravels, and clays. The upper part of the valley lies in an area in which the materials at or near the surface and for very great depths below it are composed of consolidated rocks, some of them very old and all of them considerably older than the rocks of the Coastal Plain. These two major subdivisions of the valley join each other along the Fall Line, a line—or rather a zone of varying width—that extends in a southwesterly direction through Trenton, N.J., Philadelphia, Pa., and Wilmington, Del. This line follows the Delaware River for much of the distance between Trenton and Wilmington, leaving only small areas of the Coastal Plain in Pennsylvania. From the standpoint of ground water resources, the position of the Fall Line is of the utmost importance, for it marks not only a major change in the type of rocks, but it separates an area to the southeast containing many highly productive water-bearing formations from one to the northwest in which, with few exceptions, the aquifers are generally not suitable for the development of very large ground water supplies.

The northern part of the Delaware River basin was covered by continental ice sheets at least twice, and this glaciation has left deposits of till and stratified drift in many places. The glacial deposits occur as an intermittent veneer over the surface and as a filling in preglacial stream channels.

Quality of Water

An integral part of an evaluation of the ground water resources of any region is a study of the quality of the water in its aquifers. As water percolates through the soil and flows through the underlying formations, it becomes mineralized by dissolving some of the materials with which it comes in contact. The chemical characteristics of the water determine its usefulness for various purposes. They are also a useful tool to help determine the hydraulic continuity of an aquifer. The chemical characteristics of the water in an aquifer are not necessarily constant. They tend to vary from place to place within the aquifer depending upon the character of the water entering the aquifer, upon the mineral content and solubility of the rock materials composing the aquifer, and upon the length of time the water is in contact with the rock.

Ground Water in the Area of Consolidated Rocks

The area of consolidated rocks covers about three-fourths of the drainage area of the Delaware River. However, it contains a relatively small part of the total ground water resources of the valley. The rocks are generally hard and almost all close grained, so that their pore spaces are small, and very little water can be stored in or withdrawn from them. Nevertheless, most of them, even the densest and most massive, generally have a kind of secondary porosity and permeability due to the various and sometimes numerous cracks that traverse them.

In general, the more intensely fractured rocks are the better aquifers and yield the larger quantities of water to wells. These rocks usually form aquifers that have moderately high transmissibilities. However, except in the case of some limestones, in which the fractures have been enlarged by solution, their storage capacity is not large. Sustained high yields depend, therefore, not only upon an adequate system of cracks but upon the availability of some reliable source of recharge, such as a body of surface water or a saturated overburden of permeable material. Relatively thin layers of well sorted glacial sands and gravels frequently provide such a source of recharge.

The yield of a well tapping a consolidated formation depends primarily upon the number and size of the connected openings that it encounters below the water table, or more specifically, upon their capacity to transmit water. Thus, two adjacent wells may pass through almost identical layers of rock, and one may yield a substantial quantity of water whereas the other may yield very little. It is, therefore, impossible to predict the yield of a well at a proposed site except in general terms based upon the average yield of other wells in the same strata in that vicinity. All such predictions should be qualified by a statement that the final proof must be the actual yield of the finished well, because the number and capacity of the cracks encountered cannot be determined in advance.

The capacity of the consolidated formations to store and transmit water generally decreases with depth. As greater depths are reached, the weight of the overlying materials increases and tends to close the cracks. Thus, less and less space is available to store water, and the resistance to its movement is increased. It is probable that the cracks that are horizontal, or nearly so,

are first affected and most affected in this way. The horizontal cracks tend to distribute water areally so that the tendency of the water to flow in the direction of the prevailing vertical cracks is probably accentuated with depth. The cracks along the bedding planes of flat-lying rocks, which may be numerous near the surface and are nearly horizontal, probably are less numerous and less important with increased depth.

The consolidated rocks may be listed roughly according to their average water-yielding capacities. The limestones will generally yield the largest quantity of water to wells, whereas the igneous rocks—diabase or traprock—will generally yield the least. However, it must be remembered that any such order of listing is based on average results. It is quite possible for an individual well drilled in a diabase to yield more water than a similar well drilled into a limestone, but the average yield of wells drilled in limestones greatly exceeds that of wells in the diabase. In decreasing order of expected magnitude of well yields, the consolidated rocks might be listed as follows: limestones, sandstones, shales, gneisses and schists, and intrusive igneous rocks.

The glacial deposits consist of till—an unconsolidated unstratified, heterogeneous mixture of clay, boulders, and sand—and stratified glacial drift, which is composed of sand and gravel that have been more or less sorted and stratified by the action of glacial melt waters. The hydrologic function of the deposits is twofold. First, under favorable conditions, they yield water in substantial quantities directly to wells. Secondly, they absorb and store water from precipitation and from bodies of surface water and transmit it to the underlying rocks. This second function of the deposits is more important, in the aggregate, than their direct yield to wells. Where the deposits are thick and moderately permeable, they supply large quantities of recharge water to the underlying rocks. On the other hand, where they are thin or relatively impermeable, they may fail to supply recharge to the rocks or may even retard the movement of water into them. Only in a few locations are they of sufficient thickness to yield substantial quantities of water directly to wells. Where permeable glacial material fills deep preglacial valleys, very large yields may sometimes be obtained.

In the aggregate, rather substantial quantities of satisfactory ground water are being obtained from the consolidated rocks of the upper Delaware River basin. Some of these rocks are favorable to development of moderate quantities of water, and they are capable of yielding additional quantities for future demands. Great care must be exercised in the location and spacing of wells in this area because of the limited capacities of the various aquifers for storing and transmitting water. The better aquifers are now used by a number of municipalities and industries, and further large-scale development is possible only at sites not immediately adjacent to existing installations.

With the general exception of the waters obtained from the sandstone aquifers, the waters from the consolidated rocks of the upper valley are generally moderately hard and moderately high in dissolved solids. The iron content is variable from place to place and from aquifer to aquifer. Because of their structure, some of the aquifers are rather easily polluted by surface wastes. This is particularly true of the limestones. Nevertheless, with the exercise of due care, water entirely satisfactory for most purposes can be obtained from any of the aquifers.

Ground Water in the Atlantic Coastal Plain

The formations of the Atlantic Coastal Plain consist principally of unconsolidated sands, gravels, and clays, beneath which lies the bedrock at depths

ranging from a few feet along the Fall Line to many hundreds of feet along the southern part of the coast. The Coastal Plain formations crop out at the surface in irregular, elongated bands that extend southwestward approximately parallel to the course of the Delaware River between Trenton and Wilmington. They have the general form of broad, flat sheets, sloping gently to the southeast, extending out under the ocean and presumably cropping out on its bottom at the edge of the Continental Shelf. The lower and older formations are present at the land surface near the Delaware River; the higher and younger formations crop out farther to the southeast. Although the formational units extend over wide areas and have a fairly uniform slope, this is not necessarily true of the individual beds of gravel, sand, and clay of which they are composed.

The Atlantic Coastal Plan covers about one-fourth of the drainage area of the Delaware River. However, because of the character of the material in the Coastal Plain formations, the total capacity of the aquifers in this area greatly exceeds that of the consolidated rocks of the upper part of the basin. It is estimated that the potential yield of the aquifers of the Coastal Plain portion of the drainage area is in the order of 1-1/2 to 3 billion gallons per day. At present only one-tenth or less of this potential has been developed.

With few exceptions, uncontaminated waters of the Atlantic Coastal Plain aquifers in the Delaware River basin are fairly uniform in their chemical characteristics and of excellent quality for all ordinary uses. The concentration of iron varies considerably and is sometimes objectionably high. Salinity is a problem along the lower river and the bay. Fluoride is present in moderate quantities in a few localities. There are localized areas, however, in which highly mineralized waters are obtained, owing either to the methods used in disposing of industrial wastes or to the infiltration of mineralized or contaminated surface waters into exposed aquifers. Most of these areas occur along the lower Delaware River where there are many industrial installations with a variety of wastes and where the important aquifers in the Magothy and Raritan formations are subject to recharge from the river. In spite of these problem areas, by far the greater part of the ground water from the Coastal Plain aquifers is low in mineral content and of excellent quality.

Principal Water-bearing Formations

Several of the Coastal Plain formations contain aquifers capable of yielding moderate to very large quantities of water to wells. Nearly all of them equal or exceed the capacities of the best aquifers outside the Coastal Plain. In the order of their occurrence from the Fall Line toward the southeast—that is, from oldest to youngest—the aquifers are the sands in the Magothy and Raritan formations, the Englishtown sand, the Mount Laurel and Wenonah sands, the Vincentown sand, the Kirkwood formation, and the Cohansey sand. Overlying all the Coastal Plain formations is an irregular and discontinuous veneer of Pleistocene sands and gravels, which serves to receive recharge from precipitation but, except near the mouth of Delaware Bay, is generally not thick enough to yield large quantities of water directly to wells.

The Magothy and Raritan Formations

The aquifers in the Magothy and Raritan formations are by far the most important in the Delaware River basin in both developed and potential capacity. Both formations are predominantly sand with interbedded lenses and layers of clay. The sands are believed to be interconnected, and for some

purposes these two formations might be considered as a single aquifer. Some of the clays extend for many miles, however, and at any one place there may be two or more locally distinct aquifers in each formation.

The Magothy and Raritan formations are of great importance in this area because of their ability to store and transmit large quantities of water and because of their availability in the localities where most of the industrial growth is taking place. They crop out in a belt of varying width southeast of the Fall Line and on both sides of the Delaware River. They are in hydraulic connection with the Delaware River in many places between Trenton and Wilmington, so that there is an excellent opportunity for large-scale interchange of water between the river and the aquifers.

Prior to any artificial withdrawal of ground water from them, the general movement of water in the Magothy and Raritan formations in the Delaware River basin was from their high-level intake areas northeast of Trenton and southwest of Wilmington to points of discharge along the Delaware. Large-scale withdrawals of ground water have reversed the hydraulic gradients in the aquifers in some places so that water is now moving from the river into the aquifer. Ninety percent or more of the yield of some wells is now drawn from the river, the proportion depending largely upon the distance between the well and the river. Because of the potentially high recharge wherever the aquifers are in hydraulic connection with the river, the opportunity for large-scale ground water development from the Magothy and Raritan formations along the Delaware River is probably the best that can be found within the valley. Very large quantities of excellent water can be and are even now being obtained from wells near the river.

It is important to note, however, that the aquifers along the river are already being drawn upon much more heavily than any others in the area because they occur where other conditions are most favorable to industrial development. In some places the draft upon the Magothy and Raritan formations appears to be approximately as large as can safely be maintained. In other places the aquifers seem capable of yielding substantial additional quantities of water.

Other Coastal Plain Aquifers

East of the Delaware River the depth to the Magothy and Raritan formations becomes increasingly greater, and it becomes economical to utilize other aquifers. Wells drilled into the Englishtown, Mount Laurel and Wenonah, Vincentown, and Kirkwood formations are capable of yielding moderate supplies of water for industrial and public use. However, the ability of these sands to store and transmit water is not nearly as great as that of the Magothy and Raritan formations. The Cohansey sand, which is encountered near the eastern boundary of the basin, is the youngest and uppermost major aquifer present within the Delaware watershed. The Cohansey compares favorably with the Magothy and Raritan formations in its ability to store and transmit water. It is considered to contain the last great essentially untapped source of good water within the state of New Jersey. However, the greater part of this aquifer lies outside the Delaware River watershed and is remote from the centers of industrial development in the basin. In a relatively small part of the basin near the mouth of Delaware Bay, the Pleistocene sands and gravels thicken and form an important aquifer. Some wells tapping this aquifer compare favorably with wells drawing from the Magothy and Raritan formations and Cohansey sand. Near the Delaware Bay all these aquifers are subject to salt-water contamination.

Ground-water Problems

An ever-present ground-water problem relates to the availability of ground water at a specific locality and in the desired quantities and quality. Its solution depends upon detailed knowledge of the geology and hydrology of the locality and the surrounding area. Certain other ground-water problems, though not peculiar to the Delaware River basin, are of particular interest here because they relate to contamination by industrial wastes or to recharge and possible contamination from surface streams.

Wastes dumped on the surface of the ground may lead to the contamination of the ground-water body either through direct percolation or by the leaching action of percolating waters. The shallow aquifers are more directly affected than the deeper aquifers. However, the deeper aquifers may also be contaminated if withdrawals from them have created a head differential so that the contaminated water in the shallow aquifers can move down through or around the confining clays. The action of corrosive shallow waters on well casings may also produce leaks that allow the movement of the shallow contaminated ground waters into the deeper aquifers. Rarely, the leaching of apparently innocuous material, such as that dredged from a river bottom and deposited upon the land as fill, may result in high iron or manganese in ground water.

The quality of water from a well receiving recharge from a surface stream may partly or largely reflect the quality of water in the stream and may be very different from the quality of water from another well tapping the same aquifer where it receives no such recharge. This condition has been observed at a number of locations along the Delaware River where there has been increasing mineralization of the water with the passage of time. There is generally a considerable time lag before the water that enters the aquifer from the river actually reaches the pumped well. In such cases, each increment in the mineralization of the water yielded by the well is a reflection of the quality of water that was in the river at some time in the past. This time lag is dependent upon the distance between the well and the river, which means that wells close to the river will yield water that may reflect recent quality conditions in the stream, whereas distant wells will yield water that may reflect quality conditions of some time farther in the past. This factor emphasizes the need of maintaining at all times a satisfactory quality of water in a stream that is hydraulically connected with an important aquifer, and indicates that there is no quick solution to such a water-quality problem once contaminated water from a surface stream has infiltrated into an aquifer. The proposed deepening of the Delaware River channel will greatly facilitate the movement of water between the river and the adjacent aquifers and thus enhance the need for control of the quality of the water in the river.

One of the most valuable attributes of natural ground water is its almost constant temperature throughout the year. The temperature of shallow ground-water supplies is approximately the same as the average yearly air temperature for the area in which the supplies are developed. For the deeper artesian supplies the temperature increases at a rate of 1°F for every 60 to 100 feet of depth. In those aquifers receiving recharge from surface streams, the temperature is not constant but reflects the temperature variations that take place in the streams. Again, there is a time interval involved for water of a certain temperature to move from the stream to the well. At any given time the water yielded by a well may be either warmer or colder than the water in the stream, depending upon the season of the year, the distance between the well and the stream, and the permeability of the aquifer being pumped. Temperature data have been collected from many wells near the Delaware

River, and the fluctuations in temperature that have been observed in these wells may be correlated with the temperature variations in the river water. Temperature data are thus a useful tool to determine the hydraulic continuity between an aquifer and an adjacent body of surface water.

SUMMARY

The yield of a well in the consolidated rocks of the upper valley is dependent upon the size and number of fractures encountered in the drilling of the well. Small to moderate ground-water supplies may be obtained from the aquifers in this province, but great care should be taken in the spacing of wells to reduce interference. The water obtained from the aquifers of this area is generally fairly hard and moderately high in dissolved solids. It is, nevertheless, satisfactory for most purposes, frequently without any treatment.

Moderate to very large supplies may be obtained from the aquifers in the Coastal Plain formations. Probably the best opportunity for large-scale ground-water development in the Delaware Valley can be found in the Coastal Plain aquifers that crop out along the Delaware River because of the high potential for recharge wherever the water-bearing sediments are in hydraulic connection with the river. In this respect, the maintenance of a satisfactory quality of river water is of the utmost importance because of the direct influence which the river water has on the quality of the water yielded by wells tapping exposed aquifers. The waters of the Coastal Plain are generally of good overall quality except in localized areas where they have been contaminated by industrial wastes or by recharge from mineralized or contaminated surface waters.

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c. Discussion of several papers, grouped by Divisions.
d. Presented at the Atlanta (Ga.) Convention of the Society in February, 1954.
e. Presented at the Atlantic City (N.J.) Convention in June, 1954.

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